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Experiences in renewable energy and energy efficiency in Tunisia: Case study of a developing country

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ABSTRACT

Tunisia is one of the few developing countries to have developed a proactive policy for the promotion of renewable energy and energy efficiency already in the mid-1980s. This policy gained special momentum starting in the mid-2000s, in the context of spiraling international oil prices and the development of a steadily growing energy deficit.

This momentum resulted in the development of ambitious energy efficiency and renewable energy development programs, designed to meet energy requirements in a cost-effective manner and to reduce the Tunisian economy's vulnerability to rising fossil fuel prices. The three-year (2005–2007) and four-year (2008–2011) programs as well as the Tunisian solar plan are strong indicators of Tunisia's commitment to a genuine, large-scale sustainable energy policy. They represent a framework for development and investment in renewable energy and energy efficiency in Tunisia.

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Contents

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1. Introduction

The year 2011 was a milestone year marked by a mutation in the country following the Tunisian revolution of January 14, 2011. On the international front, the year 2011 was also marked by soaring hydrocarbons prices significantly affecting the financial balance of electrical activity. Despite these difficult conditions, the Tunisian Electricity and Gas Company (STEG), the national utility company, has continued to develop its electricity and gas infrastructures and to ensure the continuity of the electricity and gas supply to citizens with the required quality. Thus, the production base has been strengthened by the addition of a combined cycle power plant new generation, single shaft passing the nominal installed capacity from 3101 MW to 3526 MW [1,2]. The transmission and distribution of electricity power has been consolidated at the end of 2011 to reach a length of about 6000 km transmission and around 150 thousand km of distribution, which has connected more than 114 thousand new customers bringing the total electrification rate to 99.6% and the total number of 3.3 million customers at the end 2011 [1].

Also in the context of policy substitution of natural gas products highly subsidized by the state, the gas infrastructure has also been a trend of 7.2% [3]. This has helped fuel a large number of new areas and promoting an addition 10% the number of gas customers registered at the end of the previous year.

The contribution of STEG program energy management was also remarkable by the spread of information points on the control of energy (PIME) to level of all units of electricity distribution and Gas Company. Also, program promoting the use of solar energy has benefited more than one hundred thousand customers for heating water and also allowed the installation of 701 facilities photovoltaic (PV) [1,4,5]. The mastery of new technologies has been the focus of the STEG Company boosting the research and development program initiated in 2010. Focuses on concentrated PV, storage of renewable energy (RE), micro-wind, hydro-turbines, solar chimneys and solar water heaters with extra gas, control of harmonic disturbances, the degradation of insulation.

On the social level, and to ensure a healthy post-revolutionary climate inside business, special trade arrangements have been made in consultation with the social partners, affecting the wage increases, the integration of agents within the subcontracting and reintegration of amnestied agents. However taking into account the events experienced by the country after the revolution, the sit-in job seekers have increased and caused a slowdown economic. This has directly affected the sales of electricity and gas industrial customers and recording a decline in demand for these products.

Also during these events, STEG was seen as an emanation of the state embodied the old regime for its role as tax collector, municipal surcharge and fee of Tunisian radio and television incorporated in the bill. This mission has affected the relationship between the company and its users who have expressed hostility towards the company and their agents and have committed acts of incivility up to slow payment of invoices. This had a direct impact on recovery efforts thereby increasing the amount of receivables at the end of 2011 to 304 Million Tunisian Dinars (MTD), over 12% of sales [5].

Aware of the difficulties faced by traders in the country and the deterioration in the purchasing power of citizens, STEG has established timelines settlement agreement with its customers for clearing their debts. As the only operator in the area, STEG is guaranteeing the continuity of service public in this new period of democratic transition that saw the country [5].

This study analyses experience with the implementation of policy support for RE technologies in Tunisia. This country, which benefit from substantial RE, has made different policy choices to encourage the market uptake of RE which could potentially satisfy a large share of their increasing energy needs, as incomes rise and contribute to managing growing electricity demand. This case illustrate lesson for other developing and emerging economies for creating a favorable environment to foster this zero-fuel energy.

The paper is organized as follows: In Section 2, Tunisian geographic position and reliefs are shortly presented. Then, the Tunisian electricity power sector is described in Section 3. In Section 4, the current state-of-the-art of RE sources in Tunisia is presented. The energy efficiency (EE) strategy is detailed in Section 5. Last section is the conclusion.

2. Tunisia country: Geographic position and reliefs

As indicated in Fig. 1, Tunisia is located in Northern Africa bordering Algeria and Libya it occupies a geographical zone between 30 and 37°N latitude and between 8 and 12°E longitude [6–8]. Tunisia′s coast to the Mediterranean Sea represents its northern and most of the eastern border. Consequently, in the northern part and along the eastern coast Mediterranean climate is prevalent. In the interior, the climate becomes more Saharan-continental as precipitation significantly declines. The Atlas Mountains are present in the northern part of the country and range from south-west to north-east. To the south of the Atlas the climate is arid throughout the year. Blowing from the desert towards the Mediterranean, the Scirocco wind is very common in spring and autumn and usually reaches the greatest wind speeds in March and in November with a maximum of 100 km/h [8].

The coasts are cut out by deep gulfs (Bizerte, Tunis, Hammamet, Gabes) and many islands (Kerkenna, Djerba, etc). Tunisia undergoes the Mediterranean influence as well as the continentalism which appears as soon as one moves away from the coast. In summer, the aridity appears by heat and the dryness related to the Saharan air flow, with the presence of the Chehili (hot wind) which blows from the desert in spring [6–8].

Tunisia is an example of a country showing marked success with its RE and EE policy support program, which has spurred similar policy initiatives in neighboring developing countries such as Egypt, Morocco and Algeria, as well as in other world regions, for example, Mexico.

3. The Tunisian electricity system

On the eve of independence, the electrical activity was managed by seven operating companies responsible for feeding the main regions of the country [5]. In 1962, the Tunisian Government has created the STEG Company to which were entrusted the generation, transmission, distribution, import and export of electricity and of natural gas [1]. Nevertheless, STEG, created in 1962, still holds the monopoly of transmission, distribution and sale of electricity (wholesale and retail). Moreover, it is the only entity allowed to import and export electricity [1,4,5].

In the generation sector, at the end of 2011, STEG still holds 87.6% (3526 MW) of the total installed capacity, considering that the whole Tunisian power generating system is around 4024 MW, the remaining 12.4% being held by [4]:

- Independent Power Producers (IPPs);
- Self-producers;
- Concessions granted under the hydrocarbon.

3.1. Electricity generation

At the end of 2011 the installed capacity of the Tunisian power generating system is around 4024 MW (including the new

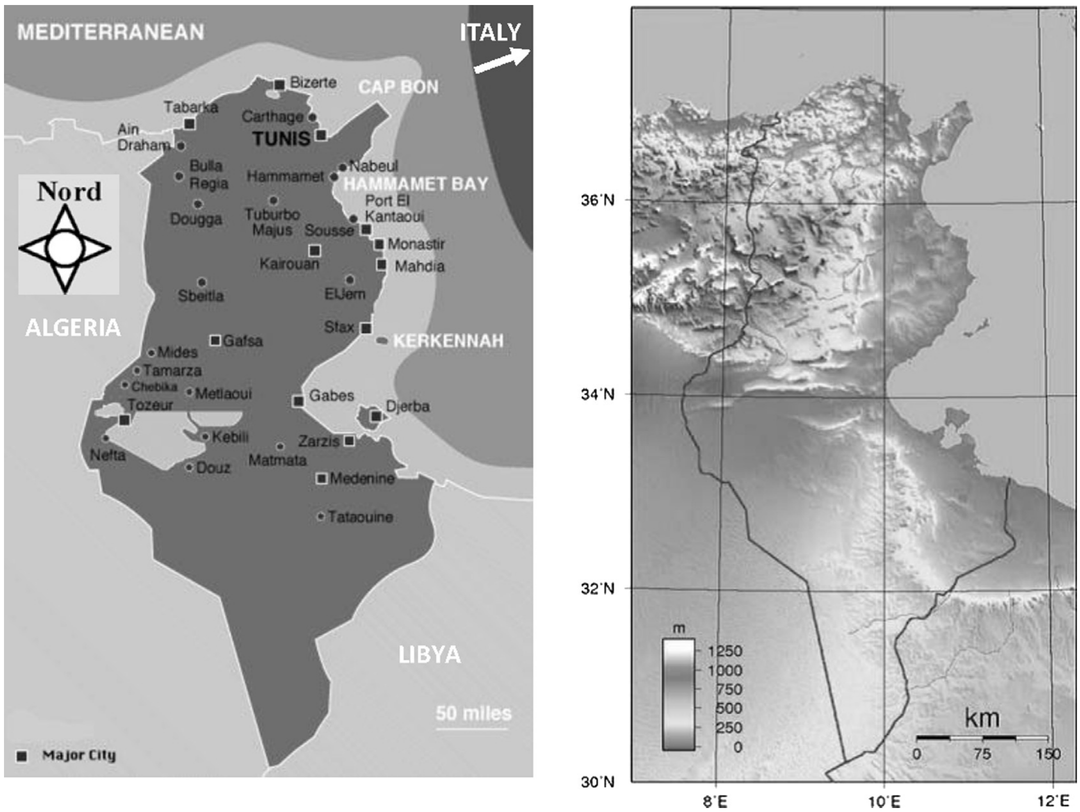


Fig. 1. Geographical position (left) and relief (right) of Tunisia [7,8].

Ghannouch facility, commissioned in 2011), of which STEG owns and operates 87.6% (3526 MW) as reported in Table 1.

The installed capacity of the national park equipment production recorded an evolution of 11.8% in 2011 compared to 2010 due to the commissioning cycle combined Ghannouch from the second half of 2011.

STEG's generating system consists of [4,5,14]:

- Gas turbines (1532 MW);
- Steam units totaling 1090 MW burning either natural gas or heavy fuel;
- The combined cycle plants of Sousse (364 MW) and Ghannouch (416 MW);
- The wind farm of El Haouaria (53 MW);
- Hydroelectric power stations with a cumulated installed capacity of 62 MW.

It is to remind that, the energy situation in Tunisia is also characterized by a heavy dependence on natural gas. The share of natural gas in the country's primary energy consumption has become increasingly significant. Tunisia receives natural gas from a pipeline between Algeria and Italy that runs across its territory.

Compared to its neighboring countries (Libya and Algeria), domestic fossil energy sources in Tunisia are limited. The Tunisian energy independence is around 78%. From 2001 Tunisia has changed its status from a natural gas exporter country to a net importer [14].

3.2. Electricity transmission and distribution

In 2009, the transmission network totaled 5787 km of which 2787 km in 225 kV, 1812 km in 150 kV and 1188 km in 90 kV [1]. The substations were 499 (117 extra high voltage (EHV)/high-voltage (HV) and 382 HV/medium voltage (MV)) with a total

Table 1
Evolution of gross installed capacity (MW).
Source: STEG annual report [1].

Types of equipment	2009	% Of the total	2010	% Of the total	2011	% Of the total
Gas turbine	1090	31.4	1090	30.3	1,090	27.1
Steam	364	10.5	364	10.1	789	19.6
Combined cycle	1406	40.5	1532	42.6	1,532	38.1
Hydro	62	1.8	62	1.7	62	1.5
Wind	53	1.5	53	1.5	53	1.3
Total STEG	**2975**	**85.7**	**3101**	**86.2**	**3526**	**87.6**
Combined cycle (Radés II)	471	13.6	471	13.1	471	11.7
Gas turbine (El Bibane)	27	0.8	27	0.8	27	0.7
Total IPP	**498**	**14.3**	**498**	**13.8**	**498**	**12.4**
National power	3473	100	3599	100	40,024	100

capacity of 20662 Mega Volt Ampere (MVA) (15020 MVA in EHV/HV and 5642 MVA in HV/MV).

At the end of 2009 the distribution network totaled 1425138 km against 138798 km at the end of 2008. MV lines totaled 50654 km and low voltage (LV) lines have reached 91859 km. The number of MV/LV substations was 57629. At the end of 2009, the number of STEG's clients reached [1]:

- 18 customers for the HV;
- 15106 customers in MV;
- 3,145,392 subscribers at the LV.

As shown in Fig. 2, the Tunisian network is interconnected with the Algerian one with two 90 kV lines, a 150 kV line, two 250 kV lines and a new 400 kV interconnection is under commissioning. Two 225 kV interconnections with the Libyan network are built

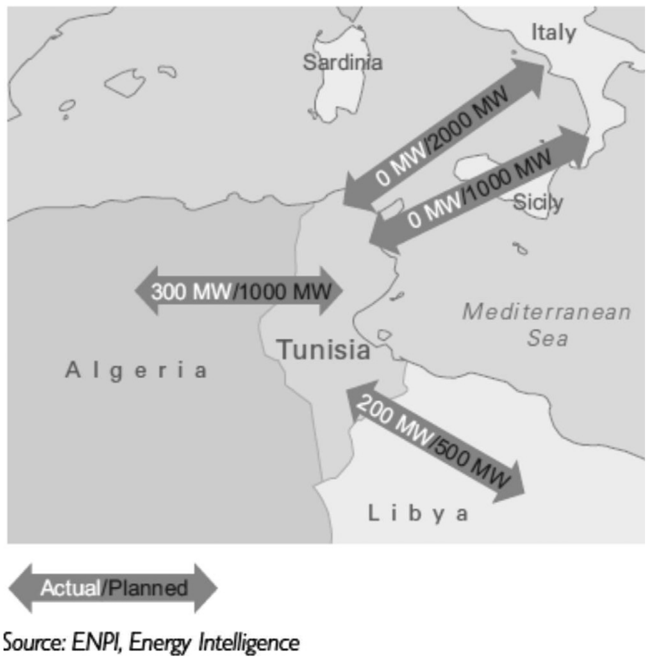


Fig. 2. Tunisia's electricity connections with neighboring countries (Libya, Algeria, and Italy).

but not functional now. Tunisia is also looking at the possibility of a transmission line running from Egypt to Morocco, whereby a feasibility study has already begun. A link between Tunisia and Italy is also being considered so that opportunities of commercializing energy can be developed between the two countries [5,9,14].

4. Strategies and objectives for renewable energies

4.1. Renewable energies

Reliance on fossil-fuel reserves and a lack of political support has meant that, historically, development of RE has not been a high priority for Tunisia's leaders. Tunisia has a long-standing interest in exploiting its RE resources, which is visible in the creation of a dedicated National Renewable Energy Agency (ANRE) in 1985, which was replaced by the National Energy Management Agency (ANME) in 2004. RE contribution in power generation can roughly be reported in Tables 2 and 3 [1,4].

As seen in Fig. 3, currently, RE play an insignificant role in total energy supply, where the integration RE rate in installed capacity varies from 0.4% in 2000 to 1.7% in 2010. Apart from centralized electricity generation from hydropower, the use of RE to produce electricity is still at an early stage of development in Tunisia country. Regarding grid-connected power plants, the focus lies currently on wind energy [9,10], although utilization of solar energy for thermal purposes is also gaining importance. In 2011, 62 MW of hydro power and 53 MW of wind power were installed according to the national utility company STEG [1,4]. According to Regional Center for Renewable Energy and Energy Efficiency (RCREEE) [2] the total installed capacity of RE was 244 MW of which 154 MW accounted for wind energy, 66 MW for Hydro and 4 MW for PV. Considering the production 54 GWh (2010: 10 GWh) were produced by hydro power and 109 GWh (2010: 139 GWh) by wind energy in 2011 as figures of STEG show. The market share of hydro-power accounted 5% in 2011 while the market share of wind energy was 9% [1]. Regarding the off-grid use of REs, 11 thousand decentralized PV systems have been installed for rural electrification [11]. An uptake of REs can be expected with law

Table 2
Contribution of renewable energy in 2011 (ktoe).

Sources	2007	2011
Wind	11	144
Hydro	17	17
Waste (landfield Jebel Chakir)	–	15
Wastes from agriculture	–	86
Total electricity	28	262
Solar water heater	15	44
Total	43	306

Table 3
Power generated from renewable energy (MW).

Projects	2007	2011
Wind	20	240
Hydro	60	60
Waste (landfill Jebel Chakir)	–	10
Total capacity	80	30

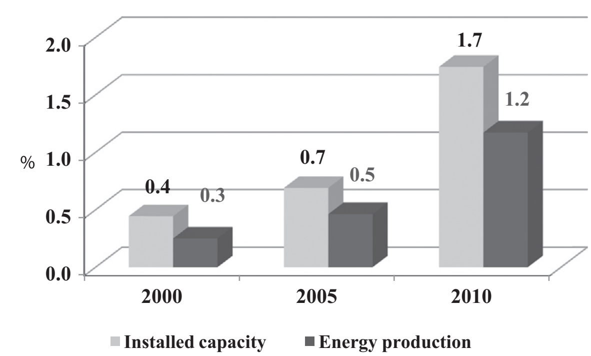


Fig. 3. Integration RE rate in installed capacity varies from 0.4 in 2000 to 1.7% in 2010.

2009-7 [12], described in more detail under "Framework Conditions for Renewable Energies" [13].

Tunis has set itself ambitious targets regarding REs. REs are given a prominent role in Tunisian energy policy. National energy policy has focused on wind energy even though solar power potentials are excellent. Promotion of REs such as financial incentives, including tax reductions and a strategy to improve EE has been helped to implement RE projects in recent years.

Presently, electricity other than for self-consumption is generated by [1,4]:

- STEG (the national utility);
- Private entities,: under IPP concession granted by the government after bidding, with STEG as sole buyer for the whole output, under a standard contract approved by the Ministry, with STEG as sole buyer for the surplus electricity generated by self producers from renewable sources or by (energy efficient) cogeneration;
- Low voltage consumers selling the surplus generated from renewable sources to the utility.

4.1.1. Solar energy

Surprisingly, RE in Tunisia is not based primarily on solar power, even though this would seem to be the most abundant national renewable resource. As shown in Fig. 4, solar radiation varies from 1800 kW h/m²/year (North) to 2800 kW h/m²/year (South). Although

the country has a very high solar potential with more than 3200 h of sunshine per year [1,6–8], and an average daily isolation of 5 to 5.5 kW h/m^2, production of solar energy is still not considered cost competitive enough, and is largely limited to use in domestic water heating systems and in certain community projects [11]. It is only now that the private sector is beginning to explore the commercial applications for solar power in Tunisia, which until recently were not sufficiently cost-effective. Solar water heaters contributed approximately 44 kilo tons of oil equivalent (ktoe) to the primary energy supply in 2011, and targets set in 2008 were to achieve a total solar water heater capacity of 740 thousand m^2 by the end of 2011.

Till the end of 2008, the use of the photovoltaic solar energy has allowed the electrification of more than 11500 isolated homes and more than 200 rural schools, the street lighting of certain number of beaches and urban parks, the installation of more than 70 solar stations of pumping of water with the aim of supplying the inhabitants in drinking water and the installation of a water desalination station with a capacity of 15 m^3/J supplied with a 10 kW PV station in Ksar Ghiléne [4] (Fig. 5).

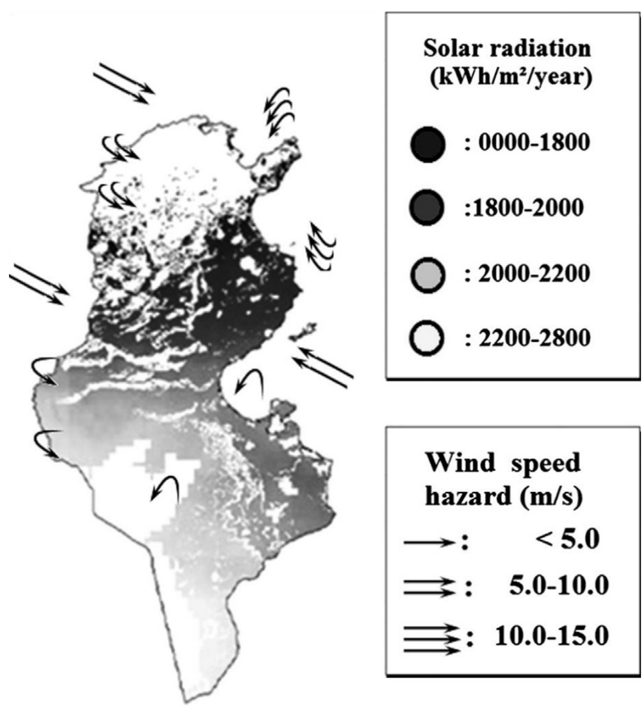


Fig. 4. Global wind speed levels along with solar radiation distribution in Tunisia. Solar resources in Tunisia: solar radiation varies from 1800 kWh/m^2/year (North) to 2800 kWh/m^2/year (South) [15].



Fig. 5. Water desalination station of Ksar Ghiléne [9].

The 2010–2016 Solar Plan covers 40 potential solar projects, and when completed, is expected to reduce national energy consumption by 660 ktoe per annum, compared to a business-as-usual scenario.

Tunisian Solar Program (PROSOL), launched in 2005, is a joint initiative of Tunisian national agency for energy conservation, state-utility STEG and Italian Ministry for Environment, Land and Sea. The program aims to promote the development of the solar energy sector through financial and fiscal support. PROSOL includes a loan mechanism for domestic customers to purchase solar water heaters and a capital cost subsidy provided by the Tunisian government of 20% of system costs, with a total installed surface in 2012 estimated to be 700 thousand m^2 (see Fig. 6). The major benefits of PROSOL are:

- More than 50 thousand Tunisian families get their hot water from the sun based on loans;
- Generation of employment opportunities in the form of technology suppliers and installation companies;
- Reduced dependence on imported energy carriers;
- Reduction of greenhouse gas (GHG) emissions.

Tunisia is also welcoming export-only projects such as TuNur, a partnership between London-based developer Nur Energie and a group of Tunisian investors, aiming at developing 2000 MW of concentrated solar power capacity in several tranches and a dedicated interconnection with mainland Italy. The Tunisian Solar Plan contains 40 projects aimed at promoting solar thermal and PV energies, wind energy, as well as EE measures.

4.1.2. Wind energy

In the northern regions of Tunisia, wind measurements revealed wind speeds of 7–10 m/s, (see Fig. 4) indicating strong potential for wind power development. Current energy output from wind farms is around 114 MW and total potential is estimated to be around 1000 MW. Therefore, while potential is not unlimited, it does provide a strong platform for growth over the coming years. Make forecast additional capacity of 692 MW through to 2016.

Studies indicate that Tunisia could eventually generate 1000 W from wind energy, and when newly launched projects are completed, this source will account for 4% of national energy production, compared with 3% in Europe and only 1% in North America. Several sites have been identified as having good potential for the use of wind power, with average wind speeds of 5.9–7.5 m/s at 80 m. Wind power generation sources totaled 240 MW in 2011, with a contribution of 144 ktoe to the national energy supply, including the 55 MW, STEG-operated El Haouaria wind farm (see Fig. 7). STEG is commissioning a further 186 MW of wind capacity at Bizerte, expected to be fully operational by September 2010.

Fig. 7 shows, the Sidi Daoud wind farm (Gouvernement Nabeul) near Cap Bon. It has been in operation since 2000. Average annual wind velocity at this location is 8.4 m/s at a height of 30 m. The wind farm is operated by STEG, and with 32 turbines each rated at 330 kW it initially had a generating capacity totaling 10.6 MW. In 2002 this was used to generate 30 GWh of electricity. In 2003 the wind farm was expanded by the addition of twelve turbines with a capacity of 8.7 MW. It now has a total generating capacity of almost 20 MW, thus representing about 0.6% of the country's installed capacity [5].

4.1.3. Biomass energy

Traditional wood and charcoal fuels are still utilized in some rural households. Projects are in place to disseminate more efficient biomass stoves. The potential for biomass gasification

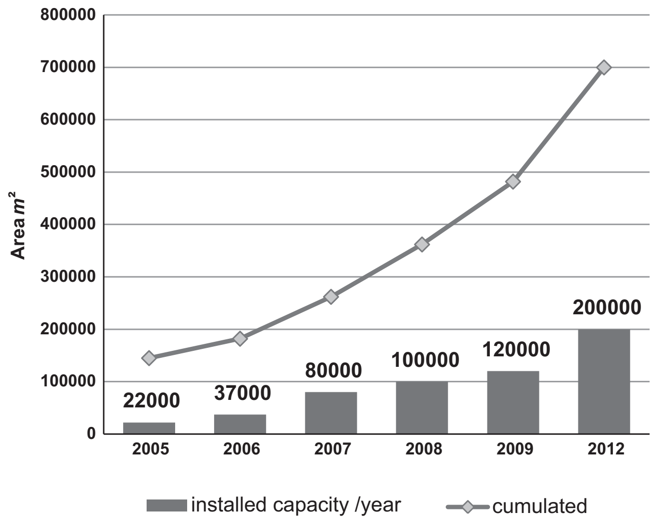


Fig. 6. PROSOL installed solar thermal water heating collectors (m²): A total installed surface in 2012 is estimated to be 700 thousand m^2.



Fig. 7. Sidi Daoud wind farm, It has a total generating capacity of almost 20 MW, thus representing about 0.6% of the country's installed capacity [5].

has been identified; a pilot project involving gasification through poultry waste has been launched. In addition, projects have been established in conjunction with Deutsche *Gesellschaft für Internationale Zusammenarbeit* (GIZ) Assistance utilising biomass energy [13]. A 10 MW waste-to-electricity project at the Jebel Chakir landfill has also recently been implemented. Domestic production of organic waste was estimated at about 6 million tons/year in 2009: 2.2 million tons of household waste; 2.2 million tons from farms and agro-industry; 1 million tons from olive oil processing; 400 thousand t from poultry droppings and 200 thousand t from waste water treatment. A proposed Government project, in collaboration with the World Bank, focuses on the rural/agro-business production of biomass.

The oil and gas sector is dominated by a public company (see Fig. 8), the Tunisian Company of oil activities (ETAP), whose mission is to manage the activities of exploration and production of oil but also of natural gas on behalf of the Tunisian state. The production is dominated by the ETAP too with an average of 50% of shares in the concessionary companies.

4.1.4. Geothermal energy

Tunisia has a substantial geothermal potential, primarily thermal waters. For example, we give in Fig. 9, the geothermal borehole in the Souk Lahad locality, Kebili area. Utilisation currently extends to the heating of greenhouses, spas, resorts and other heat-dependent activities as well as being used in ice production. Geothermal resources are taken from the 'Continental Intercalaire' aquifer: the deep aquifer or CI, which is characterized by relatively hot water (between 30 and 80 °C) and depths reaching 2800 m.

Fig. 10 shows the distribution of the geothermal resources through the country [19]. Geothermal energy allowed creation, in the south of the country, of 380 ha under greenhouse for the production of early products. It is also envisaged to arrange 300 ha in Kébili, Tozeur,

Gabès, and the extreme south, and extends to Algeria and Libya, for the production of 48 thousand tons early products intended for export [20].

4.1.5. Hydropower energy

By 2008, 62 MW of hydro-electric power generation capacity was installed in the country. 17 ktoe was contributed to the 2011 primary energy balance from hydropower. Tunisia's gross theoretical hydropower potential was estimated at 1000 GWh/year in the mid-1990s, with a technically feasible potential of 250 GWh/year. The oldest hydroelectric power plant is located in Nebeur (north of Tunisia, Gouvernement le Kef), shown in Fig. 11, dam with river on reservoir, and a design Capacity 13.2 MW. The construction of 9 further small- and mini-hydro plants, with sizes ranging from 250 kW to 3 MW, is currently ongoing [14,17].

In future, with the planned expansion of RE, particular emphasis is to be placed on the use of small-scale hydropower schemes. Nine sites for such plants have been identified in the course of a development program: Barbara (3 MW), Sidi Saad (1.750 kW), Siliana (850 kW), Bejaoua (750 kW), Medjez el Bab (250 kW), Nebhana (500 kW), Sejnane (1 MW),

Bouhertma (1.2 MW) and Khanguet Zezia (650 kW) [17].

The total capacity of the program is supposed to be 10 MW (60 GWh/a). According to a study from 1993, the total potential for hydropower in Tunisia is some 1000 GWh per year, although realistically only about a quarter of this is technically utilizable [14].

4.2. Targets and strategy of renewable energy

Tunisia's strategy for RE is clearly defined in the four-year plan extending from 2008 to 2011. The targets of the program consist in increasing the share of renewables in primary energy consumption of 4% in 2011 (without biomass and hydropower). If biomass and hydropower are included, the proportion of renewables in total primary energy consumption would be 13%. The origin of the various contributions is as follows:

Regarding solar water heating, the goal is to install 480 thousand m^2 of solar collectors from 2008 to 2011 to achieve by the end of 2011 a total installed capacity of 740 thousand m^2 and the installation of 155 thousand m^2/year. Regarding solar building, the goal is to provide a total of 3 MW peak from PV systems; power will be fed into the national grid. Of this total, 2 MW (peak) will be for the residential sector and 1 MW (peak) in the public sector, administrative buildings, hospitals, schools and universities.

A major effort is planned to develop RE applications in agriculture and in rural areas. The specific objectives that were defined are as follows [3,5]:

- Installation of 63 pumping stations and water desalination;
- Installation of 200 water pumping stations for irrigation systems by hybrid;
- Rural electrification standalone:

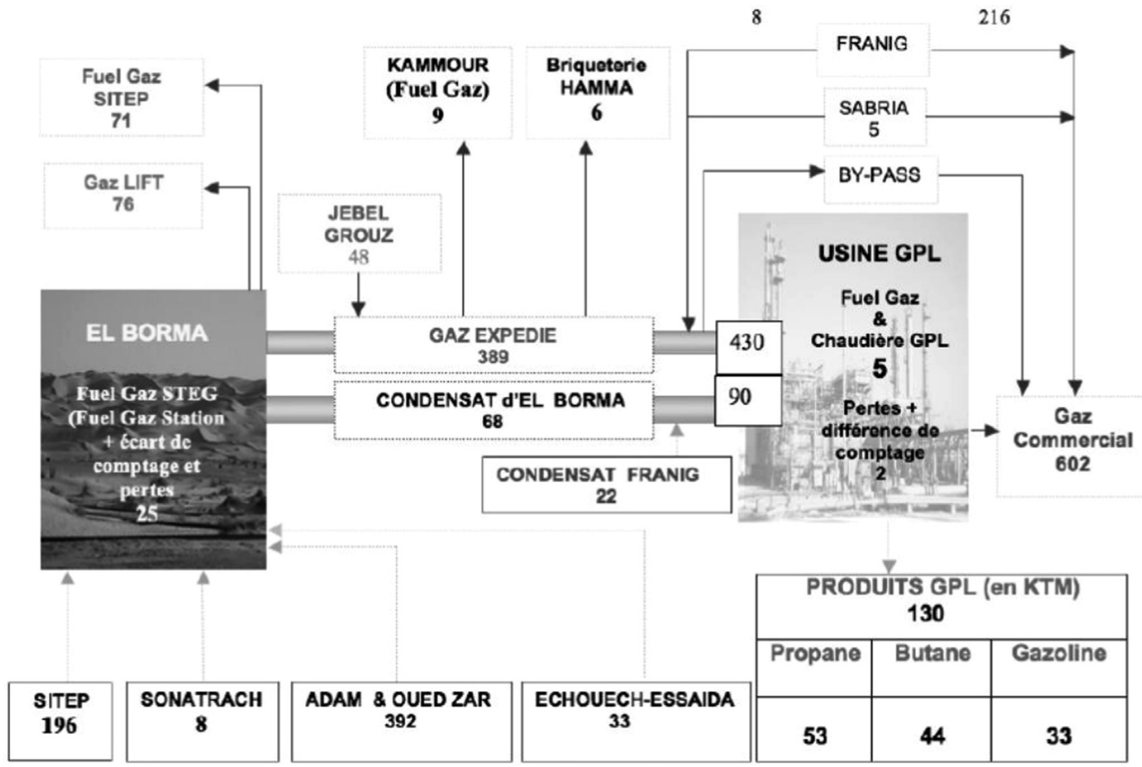


Fig. 8. Commercial gas production south; chain gas commercial south year 2011 (in Ktep) [1].

- Electrification of 1000 rural households by hybrid systems;
- Electrification of 1700 rural households by PV systems;
- Electrification of 100 farms and tourist centers by hybrid systems;
- Equipment of 200 farms with biogas units for domestic use;
- Installation of two industrial units connected to the network for the combined heat and power from biogas.

In order to strengthen national RE policy beyond the four-year plan, Tunisia has established a Tunisian solar map which incorporates in a simple concept, the whole renewable technologies and the energy effectiveness, from the point of view of the Mediterranean solar plan. The Tunisian solar plan covers the period 2010 to 2016; it comprises 40 different projects, grouped into 5 shutters. The estimated cost of the program rises to 3.369 million Tunisian Dinars (TND), which is envisaged to be financed by private and public sources distributed as follows [12,13]:

- 256 MTD for EE from the budget of National Federation of Mining and Energy (FNME);
- 596 MTD from public sector, mainly STEG;
- 2479 MTD from the private sector whose, 1074 MTD being affected to projects exporting to Europe, and 38 MTD from technical cooperation.

When the totality of the projects will have been implemented, the impact of the plan is expected to be a reduction of fossil fuel consumption of 660 ktoe per annum, which is equivalent to of 22% of the national energy consumption in 2016 [3].

Bizerte wind farm project (hereafter referred to as the project) is a newly built wind farm located on the vicinity of El Alia, Ras Jebel, Utique and Menzel Bourguiba Delegations, Governorate of Bizerte, at approximately 40 km North-East of Tunis, capital of Tunisia (see Fig. 12). The project is owned and will be operated by the STEG company.



Fig. 9. Geothermal borehole in the Souk Lahad locality, Kebili area [14].

The project comprises 143 wind turbines of 1.320 kW each, totaling installed capacity of 188.76 MW. The site of the wind farm comprises two distinct areas: the Métline area as well as the Kchabta area. The project also includes two transformation substations aimed at upgrading the power generated by the turbines to 90 kV, and the construction of three high voltage transmission lines (90 kV) to link the wind farm to the nearest central transformation stations of Menzel Bourguiba, Mateur and Menzel Jemil and connect it to the Tunisian interconnected grid. This transmission line will allow for exporting the total quantity of power generated by the project to the Tunisian interconnected grid [1,5].

The project has had an optimization and was launched in two phases:

- A first phase of 120.12 MW: 91 turbines (46 on the Métline area and 45 on the Kchabta area);
- A second phase (extension/optimization of the available area) of 68.64 MW: 52 turbines (26 on the Métline area and 26 on the Kchabta area).

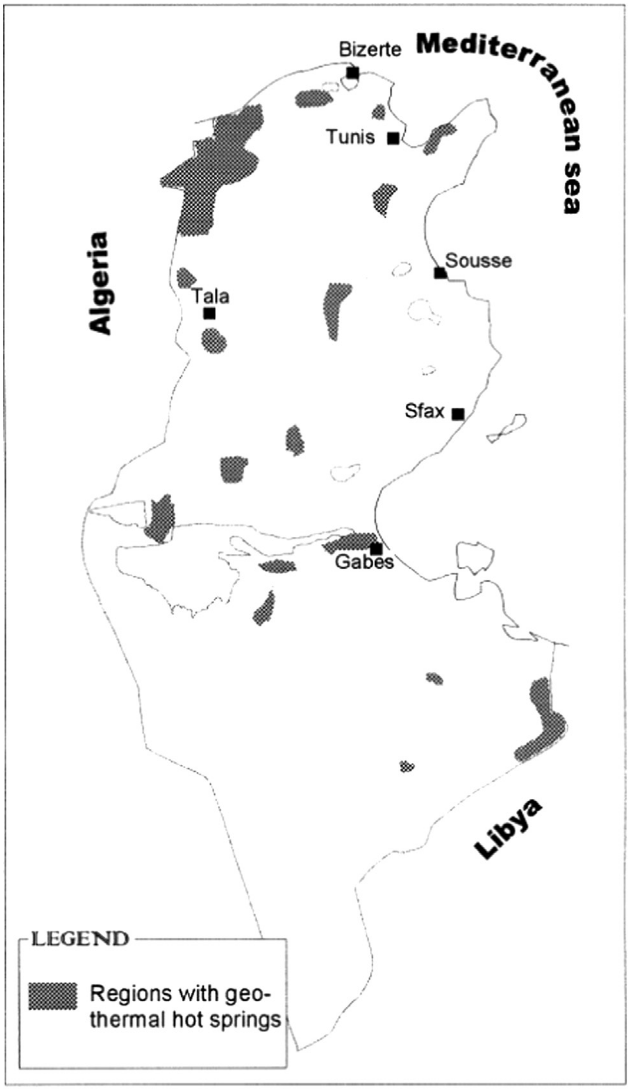


Fig. 10. Geothermal regions in Tunisia [15].

The final implementation of the project is the following: 143 wind turbines of 1.320 kW each, totalling installed capacity of 188.76 MW:

- Métline area: 72 wind turbines of 1.320 kW each, totaling installed capacity of 95.04 MW;
- Kchabta area: 71 wind turbines of 1.320 kW each, totaling installed capacity of 93.72 MW

5. Energy efficiency (EE)

Strategies that reduce energy consumption, while prioritizing how the sustainable energy sector can provide longer-term jobs, will also aid development. EE requires as much, if not more new technology and development than conventional extraction. And energy-efficient buildings, power generation, lighting and grids could revolutionise Tunisia's energy independence, while boosting the economy and enhancing the country's global reputation.

Tunisia established a program in 2000 for the rational use of energy. The Tunisian National Agency for Energy Efficiency (ANME) developed a strategic plan, which covers several fields, including [4]:

- Development and execution of the national programs of EE;
- Development of the legal and lawful framework relating to the EE;

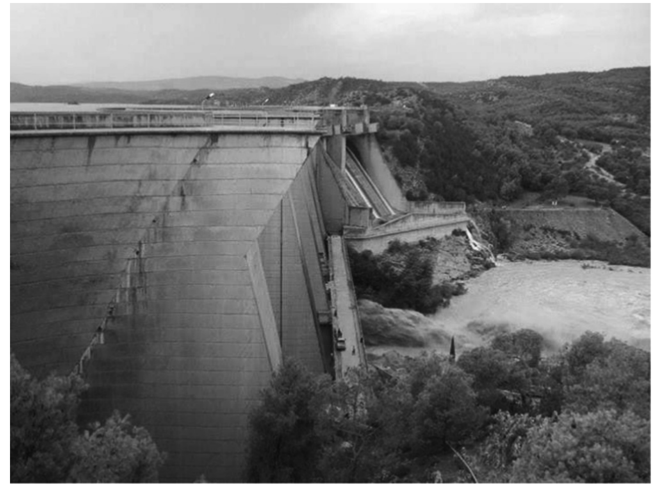


Fig. 11. Nebeur hydroelectric power plant; a dam with river on reservoir, and a design capacity 13.2 MW.

- The granting of the tax and financial incentives for EE;
- The set-up of training, education courses, and information dissemination;
- The support of the research and the development and realisation of demonstration projects;
- The encouragement of the deprived investments in this sector.

The results obtained by Tunisia at the energy intensity level help to rank it among the most efficient developing countries in terms of EE. On the EE, Tunisia passed from a surplus country (3 Mtoe at the beginning of the eighties) as an importer net of energy since 2001, see Fig. 13. This adverse balance is said to the decline of oil production of the country and the growth of the national energy demand (4.1% of average growth per year for the primary request for energy) [16,18].

5.1. Energy studies

A huge boost for Tunisian RE is the Mediterranean Solar Plan (MSP), set out as part of the Union for the Mediterranean project (UPM), which is now in its pilot phase (2009–2011). UPM's underlying idea is to set out a policy framework for RE and EE, in light of potential climate change issues the region might face in the future. Following this pilot phase, the MSP will go through a deployment phase (2011–2020), which is expected to be financed by the World Bank and the European Development Bank, with the ultimate goal of setting up an effective green electricity import-export framework under the Trans-European Networks initiative. As part of this framework, Tunisia will develop some 26 RE projects, which are expected to enable a five-fold increase in the electricity generated from renewable [3].

Tunisia is also a member of the African Maghreb Union, a regional grouping of North African countries, to promote regional integration and co-operation in terms of trade, including electrical inter-connection. The Maghreb countries interconnection project included connecting the Libyan grid to the Tunisian grid, using 220 kV transmission lines; interconnecting the Tunisian grid with the Algerian grid, on 400 kV, and interconnecting the Algerian grid to the Moroccan grid, using the same voltage.

5.2. Regulatory barriers

Programs such as the MSP are a huge opportunity for the country to develop its alternative energy market. However, now



Fig. 12. Geographical location of the wind farm: Sidi Daoud installed capacity 54 MW and Bizerte wind farm Stage A; 120 MW: has just started in February 2012.

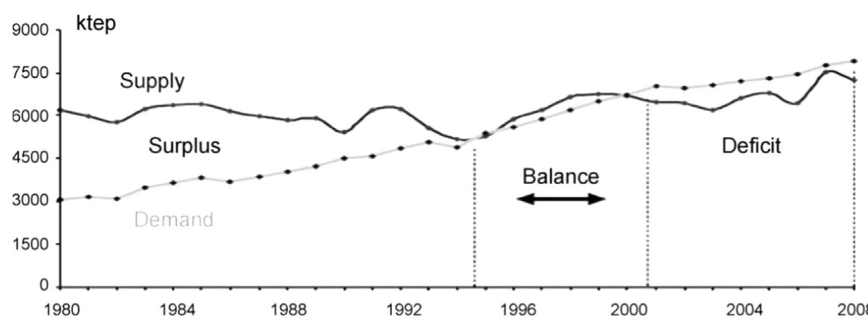


Fig. 13. Evolution of the resources and the EE in Tunisia [11,16].

that Tunisia has its renewable plan defined, and the political will has been mobilized, the challenge will be to ensure that investments are made in a constructive and beneficial way, by, for example, developing a local industry, encouraging knowledge transfer, and fostering a research and innovation.

If Tunisia is looking at developing RE on a large scale and exporting sustainable power to Europe, the price for electricity generated by renewable sources needs to be set up above market rates. While Elemd's interconnection cable is being built, such a policy would convince many investors to enter the market, and prepare the country to respond to the higher demand by developing production capacity.

Any detriment to the development of the Tunisian energy sector due to the 2011 revolution appears to have been limited. New power projects are continuing to be implemented, and operation of the country's electricity sector appears to have been unaffected. Whilst a range of financial mechanisms are available for the promotion of renewable energy sources in the country, STEG does not offer a guaranteed purchase price for self-generated electricity within the framework of a standard feed-in tariff, and as such, the current purchase agreement program that STEG operates for self-producers of electricity offers no real incentive to renewable energy producers.

5.3. STEG production program (2012–2016)

Under the development of power production, in order to meet the increasing demand estimated at 5% per year without megaprojects (Sama Dubai, Tunis Financial Harbour, etc.) and 7% per year if megaprojects are maintained, STEG program equipment includes the commissioning of three combined cycle single shaft [1,4,5]:

- A 450 MW combined cycle power plant in Sousse C that will be completed at the end of 2013;
- Another 450 MW combined cycle power plant in Sousse D that will be completed in 2015 (phase Tenders);
- A 450 MW IPP plant in Kaalet Landlous that will be commissioned in 2016 (tender is not prepared yet).

6. Conclusion

Tunisia is one of the few developing countries to have taken into account viable development energy in its strategy and set up policies and measurements in favor of energy conservation and the reduction of dependence on fossil fuels for the generation of

electricity. There is a shortage of qualified professionals in Tunisia RE and EE, such as policy analysts, teachers, scientists, researchers, engineers. It is essential to develop and implement a structural RE education and training at different levels. Tunisia RE is developing very quickly in recent years; education and training are good ways to help people keep up with the latest technology development in this field. It is also learned that RE education and training in Tunisia is facing huge opportunities as well as big challenges.

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References

[1] Société Tunisienne de l'Electricité et du Gaz (STEG): Annual report 2011, ⟨http://www.steg.com.tn/fr/institutionnel/publication/rapport_act2011/Rap_STEG_2011.pdf⟩ [accessed on-line: 11.08.2013].

[2] RCREEE Tunisia Country Profile 2012: ⟨http://www.rcreee.org/member-states/tunisia/⟩.

[3] Kanzari A. Réalisation et perspectives de projets des énergies renouvelables-SES 2009. ⟨http://www.planbleu.org/publications/atelier_energie_tunis/KANZARI_EnR_en_TUNISIE.pdf⟩ [accessed on-line: 11.08.2013].

[4] ⟨http://www.anme.nat.tn⟩ [accessed on-line: 19.08.2013].

[5] Société Tunisienne de l'Electricité et du Gaz (STEG), 2012, (Electricity Activity) Last Updated., Accessed: June 18, 2013, URL: ⟨http://www.steg.com.tn/en/institutionnel/electricite_chiffres.html⟩.

[6] Commerce et changement climatique: rapport établi par le programme des Nations Unies pour l'environnement et l'organisation mondiale du commerce. ⟨http://www.unep.ch/etb/pdf/UNEP%20WTO%20launch%20event%2026%20june%202009/Trade_&_Climate_Publication_2289_09_F.pdf⟩ [accessed online:03.06.2013].

[7] ⟨http://www.vedura.fr/environnement/climat/sommet-copenhaguechangement-climatique⟩ [accessed on-line: 07.06.2013].

[8] Initial communication of Tunisia under the United Nations framework convention on climate change; October 2001.

[9] The global competitiveness index 2009–2010 rankings. ⟨http://www.weforum.org/pdf/GCR09/GCR20092010fullrankings.pdf⟩ [accessed on-line: 12.05.2013].

[10] Ben Amar F, Elamouri M, Dhifaoui R. Energy assessment of the first wind farm section of Sidi Daoud, Tunisia. Renewable Energy 2008;33:2311–21.

[11] Benaissa A. Plan Solaire Tunisien. ⟨http://www.anme.nat.tn/sys_files/2009/plan_solaire_tun/pst.pdf⟩ [accessed on-line: 13.08.2013].

[12] Journal Official de la République Tunisienne, No. 79. ⟨http://www.profiscal.com/newfisaf/decret/D_2009-2773_af.pdf⟩; Octobre 2009 [accessed on-line:02.08.2013].

[13] Energy-policy framework conditions for electricity markets and renewable energies:23 country analyses, Eschborn, September 2007, available on ⟨http://www.giz.de/Themen/en/dokumente/en-windenergy-countrystudy-2007.pdf⟩.

[14] Tunisia—the power sector. ⟨http://www.allbusiness.com/energy-utilities/utilities-industry-electric-power-power/8942013-1.html⟩ [accessed on-line:17.06.2013].

[15] Elamouri M, Ben Amar F. Wind energy potential in Tunisia. Renewable Energy 2008;33:758–68.

[16] Belloumi M. Energy consumption and GDP in Tunisia: co-integration and causality analysis. Energy Policy 2009;37:2745–53.

[17] International Small-Hydro Atlas Website, https://cleanenergysolutions.org/content/international-small-hydro-atlas-website [accessed on-line:12.08.2013].

[18] Ben Jannet Allal H. Energie et Ecodéveloppement en Tunisie. Report of Helio International. ⟨http://www.helio-international.org/reports/pdfs/Tunisie-FR.pdf⟩ [accessed on-line:02.09.2013].

[19] Bouguecha S, Hamrouni B, Dhahbi M. Small scale desalination pilots powered by renewable energy sources: case studies. Desalination 2005;183:151–65.

[20] Tunisie: perspectives d'utilisation des énergies renouvelables dans le domaine agricole. ⟨http://www.riaed.net/spip.php?⟩article1444 [accessed on-line:17.08.2013].